# Supplementary Information

## Insights into the assembly rules of a continent-wide multilayer network

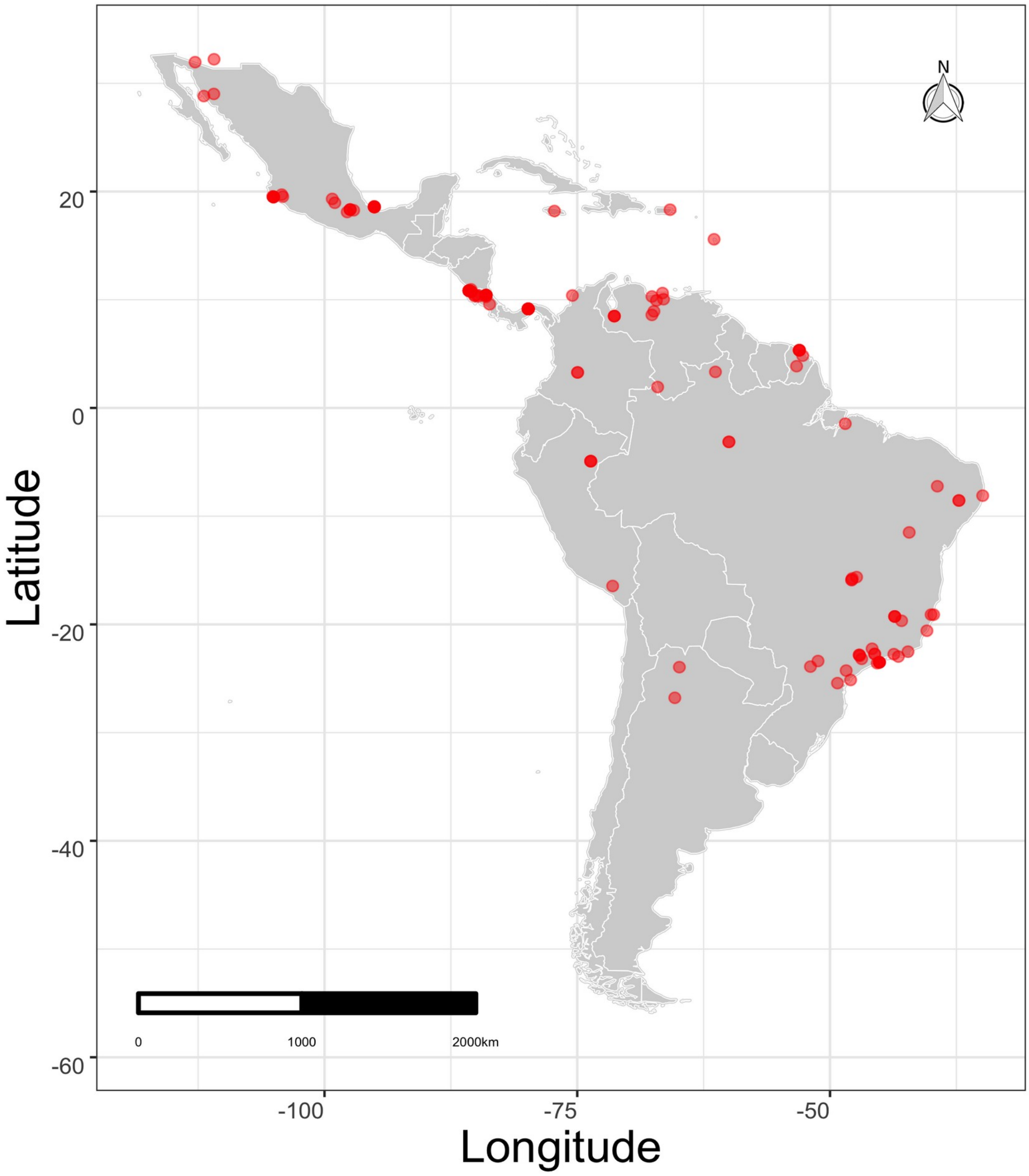
## Supplementary Data 1

Supplementary Data 1. Dataset used to build the multilayer network, including an R code for drawing it. Available on GitHub via Zenodo: https://doi.org/10.5281/zenodo.1487572.

## Supplementary Data Sources 1

Map of the study sites and list of references used to build the dataset on bat-plant interactions in the Neotropics.

**Supplementary Figure 1. Map of the study sites.**



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## Supplementary Methods 1

Details on the calculation of centrality, definition of the multilayer structure, and calculation of multilayer versions of centrality metrics.

### 1. Calculation of centrality

First, we analyzed centrality in the multilayer network, considering its layers (frugivory and nectarivory) separately. For each bat species on each layer, we calculated seven metrics of centrality that are commonly used in ecological studies[1–3]: normalized degree (*ndeg*), closeness (*clo*), betweenness (*bet*), specialization (*d'*), eigenvector (*eig*), within-module degree (*lpa.z*), and participation coefficient (*lpa.c*).

The metrics degree, specialization, within-module degree, and participation coefficient were calculated using the original bipartite structure (two-mode) of each layer. As the other centrality metrics can be calculated only for unipartite networks (one-mode), in the cases of closeness, betweenness, and eigenvector, we transformed the original layer into two unipartite projections of bats and plants. In each projection, two bat species are connected to one another if they share at least one common visited plant species in the original network. Link width in those projections is, thus, proportional to the number of shared species between each pair of species. We focused on the bat projections in those cases, as bats are the consumers in our conceptual framework (the IHS[4–6]). Centrality metrics were calculated using the packages *igraph*[7] and *bipartite*[8] for R[9].

It should be mentioned that the relationship between centrality metrics may not be trivial in structured networks. Thus, we have considered several metrics to get an accurate characterization of centrality in the studied interaction networks. In the following pages, we introduce these metrics.

Degree is the simplest centrality metric and was calculated as the number of plant species with which a given bat species interacts[10], i.e., it is the number of links made by each bat and plant species in the network. This metric was normalized by dividing the number of links of the bat species by the total number of plant species in the network (i.e., its potential number of partners). Biologically, normalized degree may be interpreted as a proxy for niche breadth[1]. As our network comprises data from the whole geographic distribution of those bat species, normalized degree is a proxy for fundamental niche breadth.

Closeness centrality was calculated as the average distance between a given bat species and all bat species in the network, where the distance is given by the number of links between them (i.e., in a path)[11]. In other words, bat species with higher closeness values have a greater niche overlap with other bat species. Biologically, closeness may be interpreted as a proxy for niche commonness in contrast to niche ubiquity. In other words, how much the niche of a species overlaps with the niche of other species or is segregated[1].

Betweenness centrality was calculated as the proportion of shortest paths in which a given bat species is present[12]. A shortest path is a geodesic, i.e., the shortest possible set of links that separates two species. Biologically, betweenness may be interpreted as a proxy for the role of a species in binding different guilds within the network.

Specialization was measured as the selectiveness of the set of interactions made by a bat species in relation to the interactions made by all other bat species in the network[13]. Biologically, when a bat species consumes the fruits or flowers of a set of plant species that are not strongly consumed by other bat species, it has high specialization.

Eigenvector centrality was calculated considering the contribution of a given bat species to the main eigenvector of the network, i.e., the eigenvector associated to the largest eigenvalue of the adjacency matrix[14]. This metric is very similarly to the PageRank centrality used by Google to rank webpages[15]. In other words, a bat may have a high eigenvector score by either having high degree, being connected to vertices that also have high degrees, or both. This value is related to the transition matrix, which is related to random walks in the network. This probability of transition between two nodes of $i$ and $j$ could be calculated both for weighted and binary networks. For un-weighted network it is calculated as $P_{ij}=\frac{A_{ij}}{k_i}$, in which $k_i$ is the degree of node $i$, and $A_{ij}$ is from adjacency matrix. Similarly, for weighted network it is considering as $P_{ij}=\frac{W_{ij}}{s_i}$, in which $W_{ij}$ is the weight of connection between nodes $i$ and $j$, and $s_i$ is the strengthen of the connections connected to node $i$ ($\sum_j W_{ij}$). Biologically, eigenvector centrality may be interpreted as a proxy for how influential a bat species is in maintaining mutualistic services, as it combines information of niche breadth and role in binding guilds.

Within-module degree and participation coefficient are centrality metrics calculated in conjunction with a modularity analysis based on optimization and functional cartography[16]. Here, we used new versions of these metrics based on results from the new LPA modularity optimization algorithm[17]. Within-module degree was calculated as the number of links made by a given bat species within its module, normalized as a Z-score. A participation coefficient was calculated as the proportion of links made by a given bat species with bat species from other modules. Biologically, within-module degree may be interpreted as a proxy for niche breadth within a guild, while participation coefficient is a proxy for the role of a species in binding different guilds within the network.

Although each centrality metric captures a different aspect of the relative importance of a bat species for the structure of its network, some of them overlap in their concepts and calculation. Therefore, some metrics might be correlated with one another. We present in Supplementary Results 1 some correlograms of centrality to clarify those relationships. To better visualize how different centrality metrics vary between layers for each of the most central bat species, we also drew spidercharts (Figure 2 in the paper).

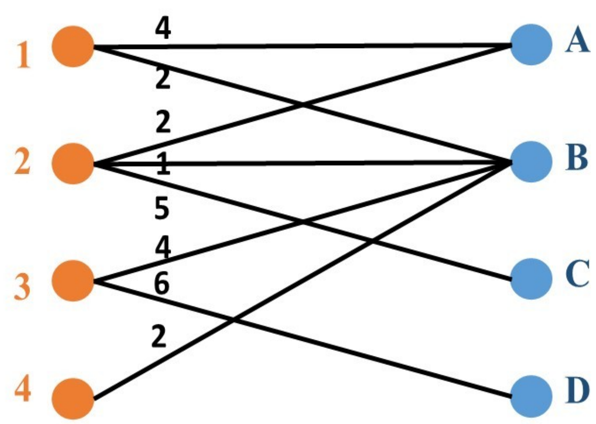
To assess the relative importance of each bat species to the structure of the complete multilayer network, we used a new multilayer approach, as described in section 3 of this supplement.

## 2. One-mode projection methods

There are three methods for separating a two-mode (bipartite) network into two one-mode (unipartite) projections[18]. In the calculations done through all the paper, the binary method was used as it is the simplest way of calculating the weights between connections. We explain them as follows.

### *2.1 Summation method*

In this method, we consider the weighted two-mode network as in Fig. 1. The nodes of this network represent whole species: letters stand for plants and numbers stand for bats. The links are weighted as indicated by the numbers written on the lines.



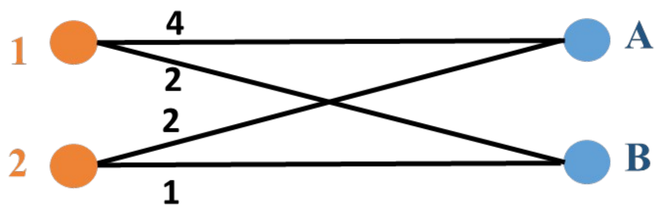

Supplementary Figure 2: The original two-mode network of bats (numbers) and plants (letters).

For decomposing the two-mode network into two one-mode projections, we proceeded as follows. First, as shown in Fig. 2, we select one set of nodes, for example, plants. We see that node A is connected to node 1 with weight 4, and it is also connected to node B with weight 2.

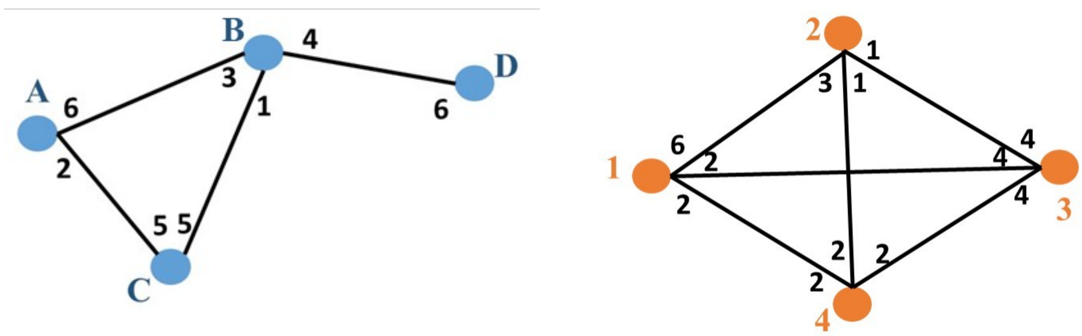
Node A is connected to node 2 by weight 2 and node 2 connected to node B by weight 1. Therefore, node A has two possible paths to reach to node B: through node 1 and through node 2. If we sum the weights of the paths from node A to nodes 1 and 2, the result is: 2 + 4 = 6.

Now we need to consider the opposite: from node B to node A. Here we have: node B may reach node A over two paths: one through node 1 with weight 2 and the other through node 2 with weight 1. Therefore, the path B→A has weight 1 + 2 = 3. This way, the one-mode projection becomes a **weighted directed network**.

Figs. 2 and 3 provide a visual explanation of this one-mode projection method:




Supplementary Figure 3: Alternative paths between vertices in a two-mode network, including their respective weights. This is a subset of the network presented in Fig.1.



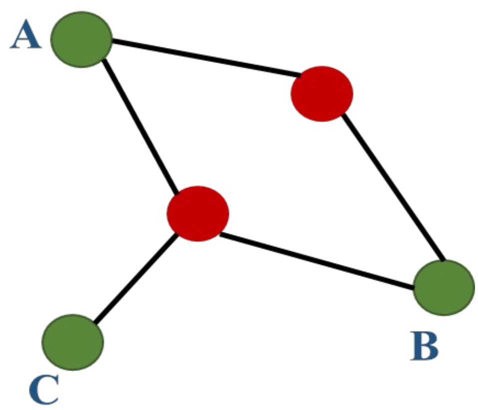

Supplementary Figure 4: Two one-mode projections for plants (letters) and bats (numbers).

### *2.2 Binary method*

The other method for making one-mode projections is the binary method, which we used in the present study. In this method, each link is considered as having weight 1, and the number of alternative paths is considered the link weight.

For example, in Fig. 4 we see that node A is connected to node B through two paths. Therefore, the weight of the connection between A and B in the one-mode projection is 2. This method produces a **weighted undirected network**.

As nodes A and C are connected through only a single path, the weight of their connection is 1. And so forth.




Supplementary Figure 5: Example of a two-mode network that may be decomposed using the binary and Newman methods.

### *2.3 Newman method*

Finally, we explain the Newman method. In this method, we calculate link weight using the following function:

$$W_{ij} = \sum_p \frac{w_{i,p}}{N_p - 1}$$

Where:

- $i$ and $j$ are the nodes of interest;
- $p$ is the node in-between two nodes of interest;
- $N_p$ is the number of links of the node in-between;
- $w_i$ is the weight each link of the node in-between.

For example, if we consider all weighs of the links in Fig. 4 as having value 1 (for simplicity), we need to calculate the connection between nodes A and B as follows. In one path, node A is connected to a node in-between that has 3 links. In the other path, node A is connected with a node in-between that has 2 links. This method produces a **weighted undirected network**.

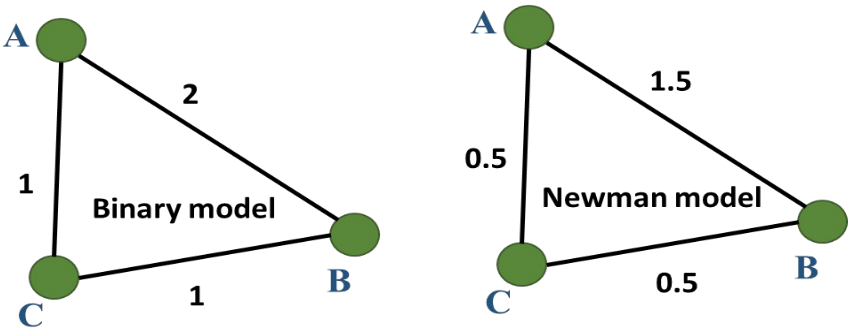
Therefore, we make the summation as follows:

A→B: $w_{A \to B} = \frac{1}{3-1} + \frac{1}{2-1} = 0.5 + 1 = 1.5$

A→C: $w_{A\rightarrow C} = \frac{1}{3-1} = 0.5$

B→C: $w_{B\rightarrow C} = \frac{1}{3-1} = 0.5$

Partial examples of one-mode projections built using the binary and Newman methods are presented in Fig. 5.




Supplementary Figure 6: One-mode projections built using the binary and the Newman methods.

## *2.4 Multilayer network*

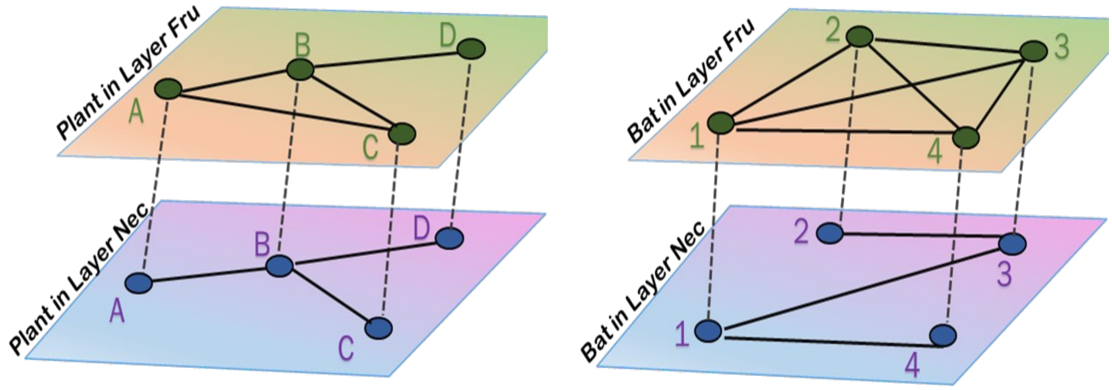
Using the one-mode projections built for each type of link (layer) we can build a multilayer network[14].

In our dataset, we have two layers represented by two types of links between bats and plants: frugivory and nectarivory. Each layer, therefore, contains two node sets: bats and plants.

After using any of the one-mode projection methods explained in the previous sections, we get four networks: two one-mode projections for bats (frugivory and nectarivory) and two one-mode projections for plants (frugivory and nectarivory). To build a multilayer network, we need again to select which node set is going to be the focus: bats or plants.

The studied network is classified as a **multiplex network** within the family of multilayer networks, because it is node-aligned, equally sized, and diagonally coupled[19,20]. For a multilayer network, **interlayer links** are defined by connecting each node in each layer to itself in the other layer with the weight calculated as the average value for both layers. Interlayer links are defined for a given node only when it participates in more than one layer. For example, a bat species that makes both interactions of frugivory and nectarivory with plants participates in both layers and, therefore, receives an interlayer link.

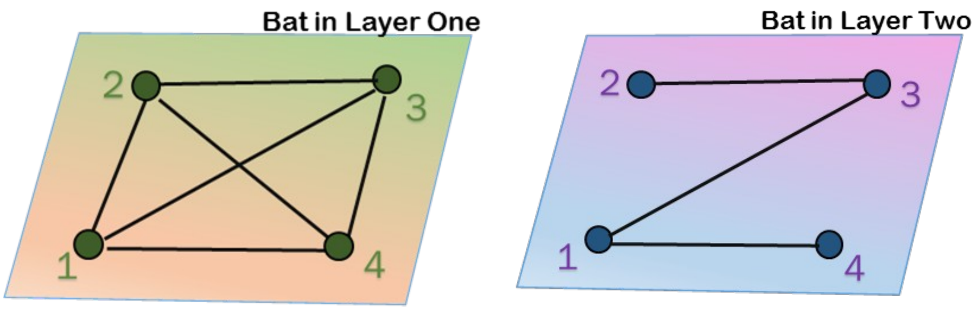
For example, let us use the summation method and build two multilayer networks as shown in Fig. 6.




Supplementary Figure 7: Multilayer one-mode networks for plants (left) and bats (right). Each layer represents an interaction type: frugivory or nectarivory. Interlayer links are defined by connecting each node to itself in the other layer.

## 3. Centrality in a multilayer network

Considering 4 nodes on each layer, linked to one another as shown in Fig. 7, we may define the edge lists of the layers as follows. For simplicity, we consider intralayer and interlayer link weights equal to 1.




Supplementary Figure 8: Bat species connected to one another in two layers of the network.

| Layer 1 | | Layer 2 |
|---|---|---|
| 1→2 | 3→1 | 2→3 |
| 1→3 | 3→2 | 1→4 |
| 1→4 | 3→4 | 3→2 |
| 2→1 | 4→1 | 4→1 |
| 2→3 | 4→2 | 1→3 |
| 2→4 | 4→3 | 3→1 |

In the multilayer network, each node is connected to itself in different layers. Then, for combining two layers and avoiding ambiguity, we rename the nodes in layer 2 sequentially as follows:

$2 + 4 \rightarrow 3 + 4$ is renamed as: $6 \rightarrow 7$

$1 + 4 \rightarrow 4 + 4$ is renamed as: $5 \rightarrow 8$

$3 + 4 \rightarrow 2 + 4$ is renamed as: $7 \rightarrow 6$

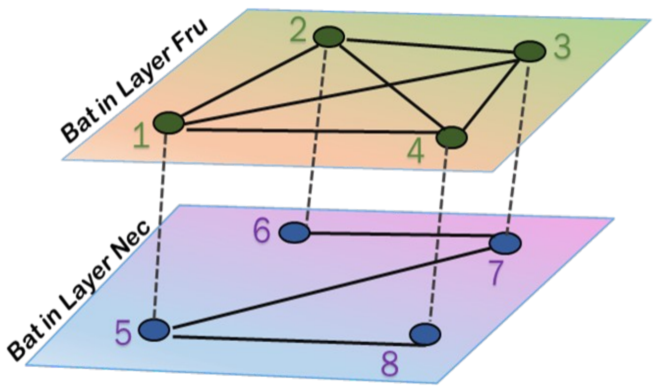
$4 + 4 \rightarrow 1 + 4$ is renamed as: $8 \rightarrow 5$

$1 + 4 \rightarrow 3 + 4$ is renamed as: $5 \rightarrow 7$

$3 + 4 \rightarrow 1 + 4$ is renamed as: $7 \rightarrow 5$

As the total number of nodes in each layer is 4, in the second layer, we sum the node labels by 4.

The result is a multilayer graph and a multilayer edge list as shown in Fig. 8.




Supplementary Figure 9: Multilayer network bats species with nodes sequentially renamed.

Multilayer edge list:

| | | | | |
|---|---|---|---|---|
| 1→2 | 3→1 | 6→7 | 3→7 | 5→7 |
| 1→3 | 3→2 | 5→8 | 4→8 | 7→5 |
| 1→4 | 3→4 | 7→6 | 5→1 | |

| | | | |
|---|---|---|---|
| 2→1 | 4→1 | 8→5 | 6→2 |
| 2→3 | 4→2 | 1→5 | 7→3 |
| 2→4 | 4→3 | 2→6 | 8→4 |

Now we may calculate the centrality of each node in the multilayer network. Let us use degree centrality of an undirected network as an example:

| | |
|---|---|
| Node 1 = 4 | Node 5 = 3 |
| Node 2 = 4 | Node 6 = 2 |
| Node 3 = 4 | Node 7 = 3 |
| Node 4 = 4 | Node 8 = 2 |

Then we need to integrate results for different layers. For example, as nodes 1 and 5 are the same node on different layers, we use both values to calculate its multilayer centrality:

Node 1 and 5 = 4 + 3 = 7

Node 2 and 6 = 4 + 2 = 6

Node 3 and 7 = 4 + 3 = 7

Node 4 and 8 = 4 + 2 = 6

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# Supplementary Methods 2

Details on the calculation of phylogenetic and geographic signals.

## 1. Data sources

We used a combination of analyses to detect the signals of the geographic distribution and phylogeny of bats at different scales of the multilayer network.

In this analysis we used only the bat species that belong to the main component of the network, whose distribution data were present in the IUCN database (65 bat species). First, we computed five pairwise distance matrices for bat species: phylogenetic, geographic, interactions, modules, and layers.

To generate the phylogenetic distance matrix, we used the branch lengths from the most up-to-date, species-level phylogeny of phyllostomids [1]. However, out of the 65 bat species used in our analysis, 8 were not included in the phylogeny. To solve this problem, in each comparison involving one of those absent species, we calculated the distances considering all species of the same genus present in the tree and averaged the values.

For example, the species *Anoura fistulata* was not included in the phylogeny, but *Anoura caudifer*, *Anoura geoffroyi*, and *Anoura latidens* were. Thus, to set the distance between a given bat species and *Anoura fistulata*, we computed the phylogenetic distance of this bat species to each of the other three *Anoura* species, and calculated the average distance. Since neither the species *Lichonycteris obscura* nor any species of the genus *Lichonycteris* was present in the phylogeny, we used the phylogenetic distances of the related species *Hylonycteris underwoodi* to replace it as they are sister clades.

## 2. Calculation

To generate the pairwise geographic distance matrix, we used the distribution of bat species recovered from the IUCN database. The distance between any two species was calculated as 1 minus the intercept area of the distributions divided by the union area of the distributions—an equivalent of Jaccard index of dissimilarity.

For the pairwise interaction distance matrix we measured the dissimilarities of the subset of plants used by each bat species, using the Jaccard distance. As the pairwise modules distance matrix we used a matrix of dummy variables. Each cell was assigned value 0, if the two species belonged to the same module, or 1, if the two species belonged to different modules. To measure the pairwise layer distance we measured the richness of plant species used by each bat species in each layer of the network and then computed the Jaccard distance index.

To test the signals, we used Mantel and partial Mantel tests. In each Mantel test we calculated the correlation between two distance matrices (e.g., interaction and phylogenetic, for the phylogenetic signal in interactions), and compared the results against the correlation found in randomized matrices generated with a null model. The partial Mantel test is also aimed at testing the correlation between two matrices, but it is conditioned by a third matrix (e.g., interaction, phylogenetic, and geographic, for the phylogenetic signal in interactions discounting the geographic signal). All Mantel and partial Mantel tests were based on Spearman correlations, and 10,000 randomized matrices were used in each null model. We used as a measure of effect size the Z-score (observed correlation minus the average correlation of the null matrices, divided by the standard deviation of the null matrices).

To test whether interaction types were uniformly distributed among modules or whether each module was related mainly to one layer of the network, we used a chi-squared test of independence. We removed modules with only a single bat species from this analysis. At last, using a Mantel test we tested for a phylogenetic signal in bridge species (species that belong to both layers of the network), i.e. whether bridge species we more phylogenetically closer than randomly expected.

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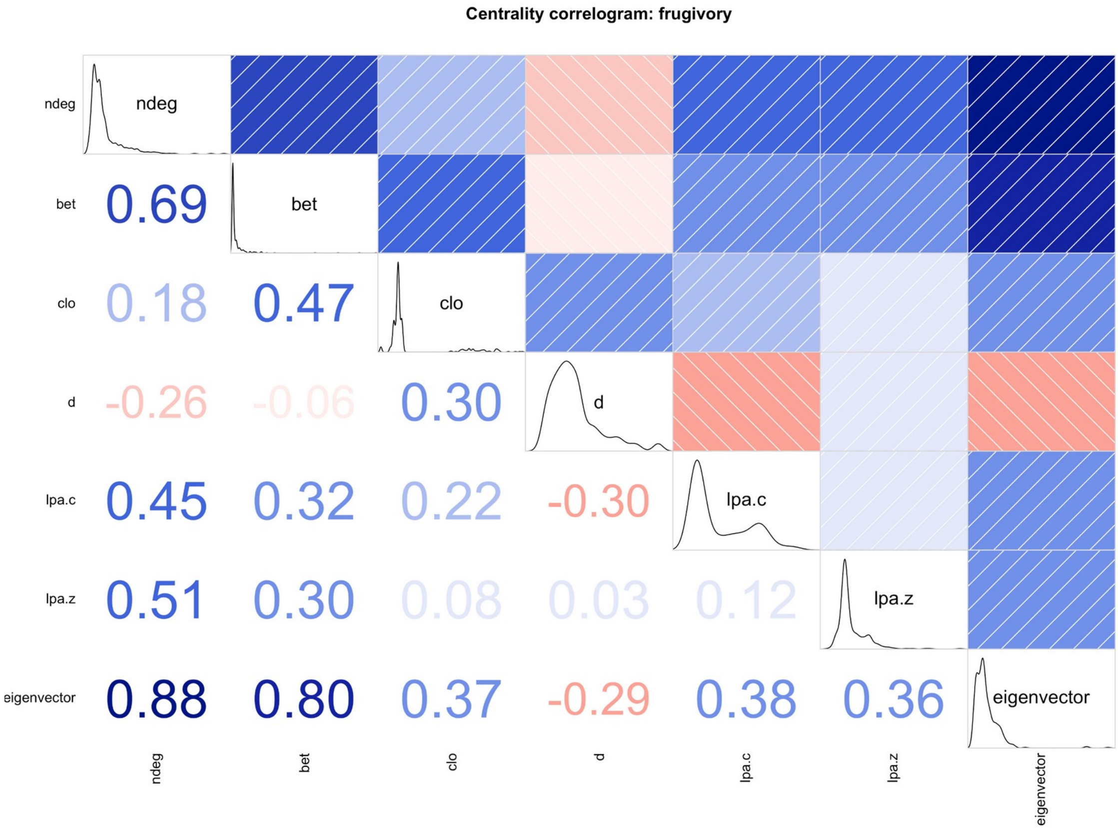
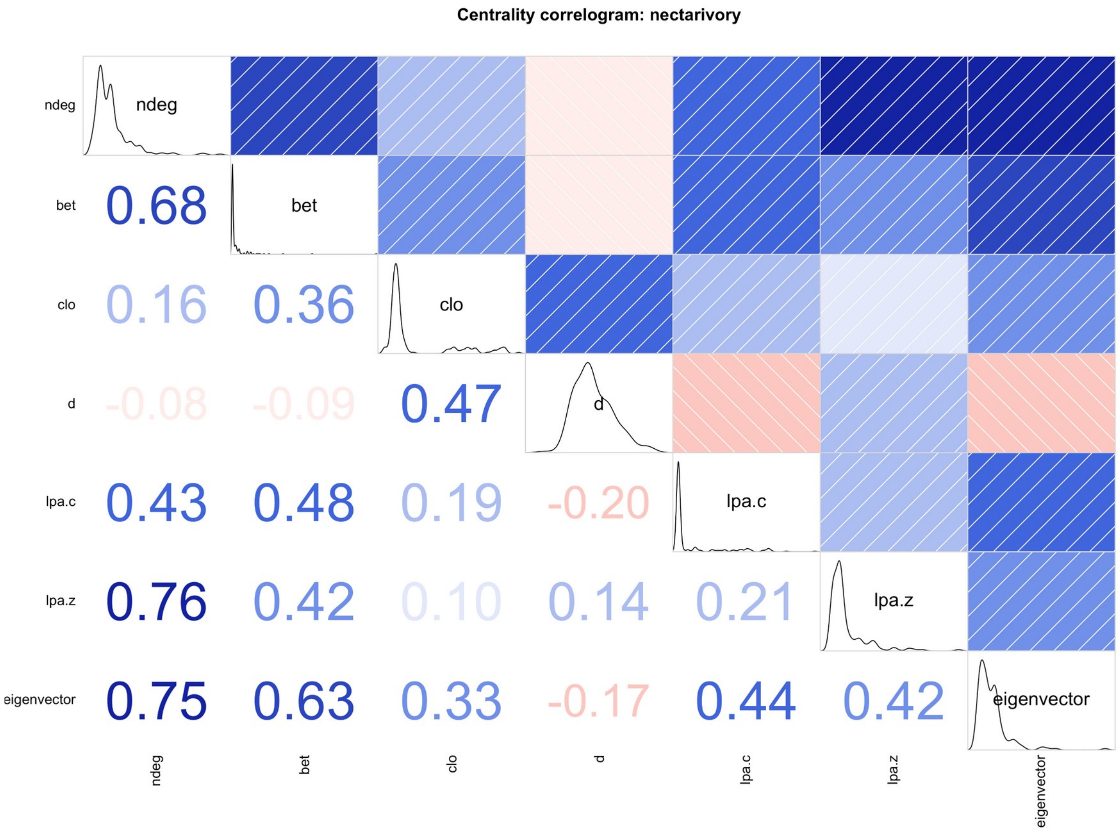
## Supplementary Results 1

Correlograms of centrality and traits for each layer and the entire network. A – frugivory, B – nectarivory, C – dual, D – multilayer, E - traits. In the matrix, the lower triangle presents scores of the Pearson correlation statistics, the upper triangle presents the same scores as a red-blue color scale (negative-positive), and the diagonal presents the distribution of each centrality metric. Abbreviations: frug = frugivory layer, nect = nectarivory layer, dual = dual interactions, mult = multilayer, ndeg = normalized degree, bet = betweenness, clo = closeness, d' = specialization, lpa.c = within module degree, lpa.z = participation coefficient, and eigenvector = eigenvector centrality. See methods for details on the calculation of each metric.

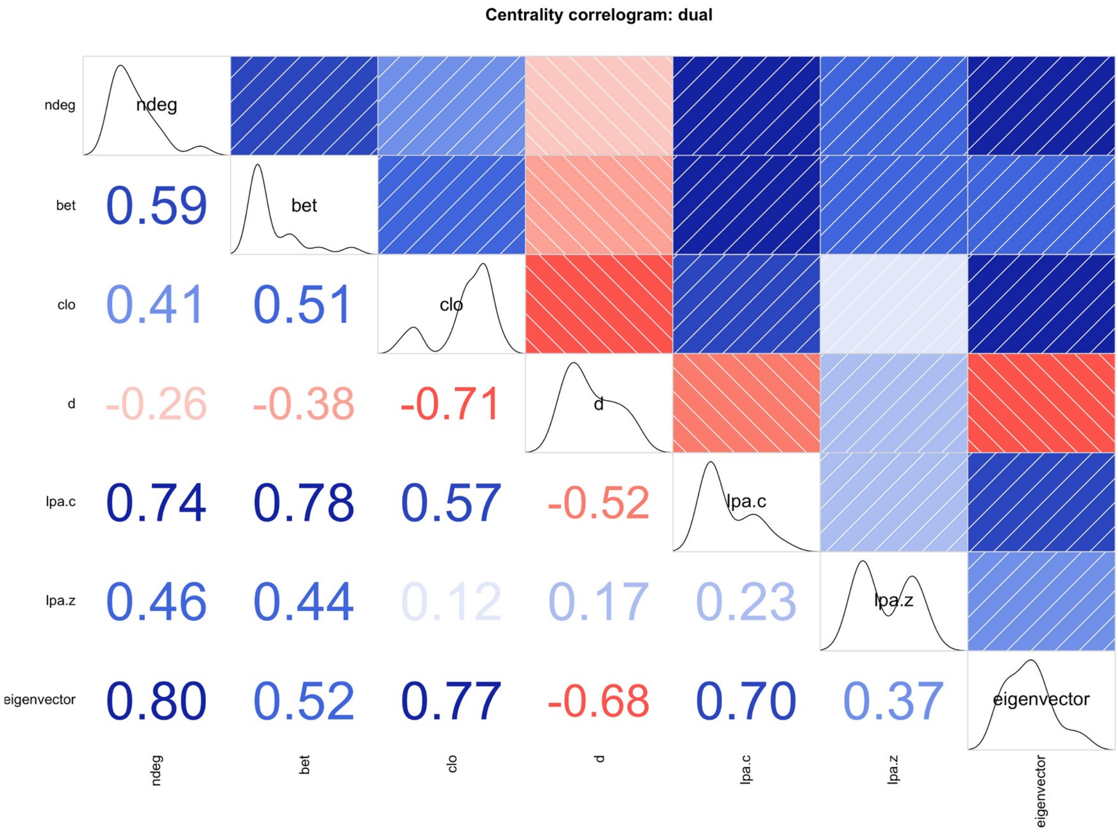
### Supplementary Figure 10. Frugivory



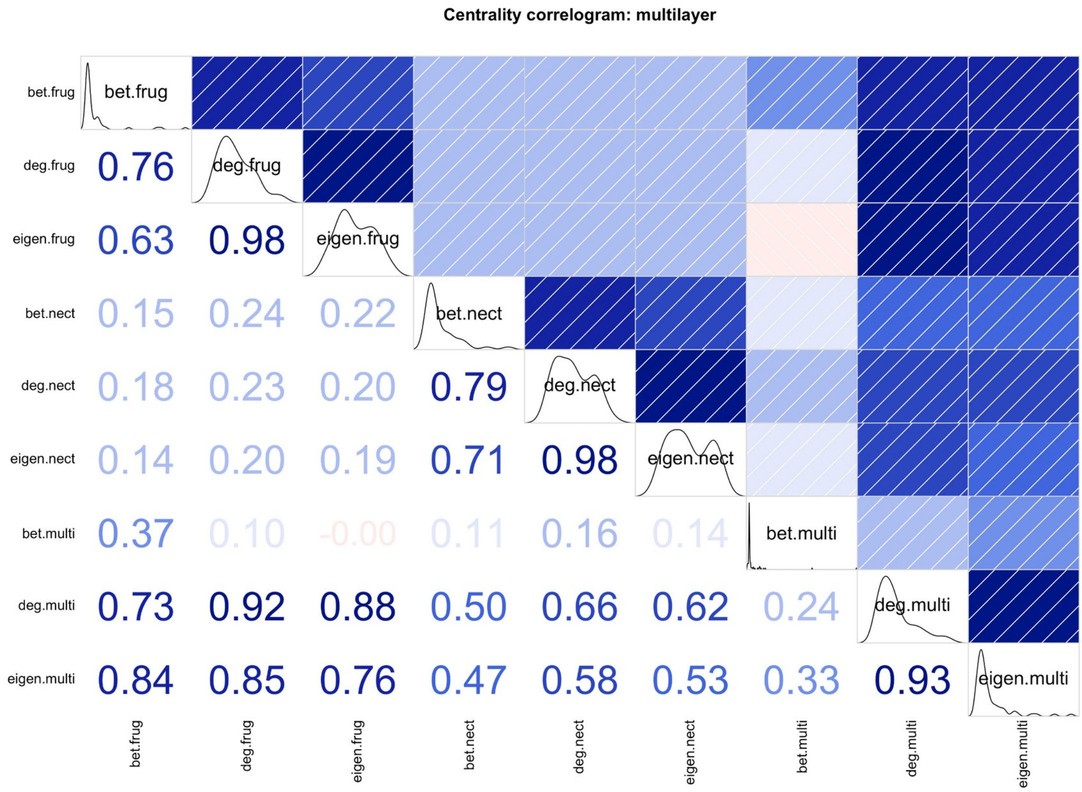
## Supplementary Figure 11. Nectarivory



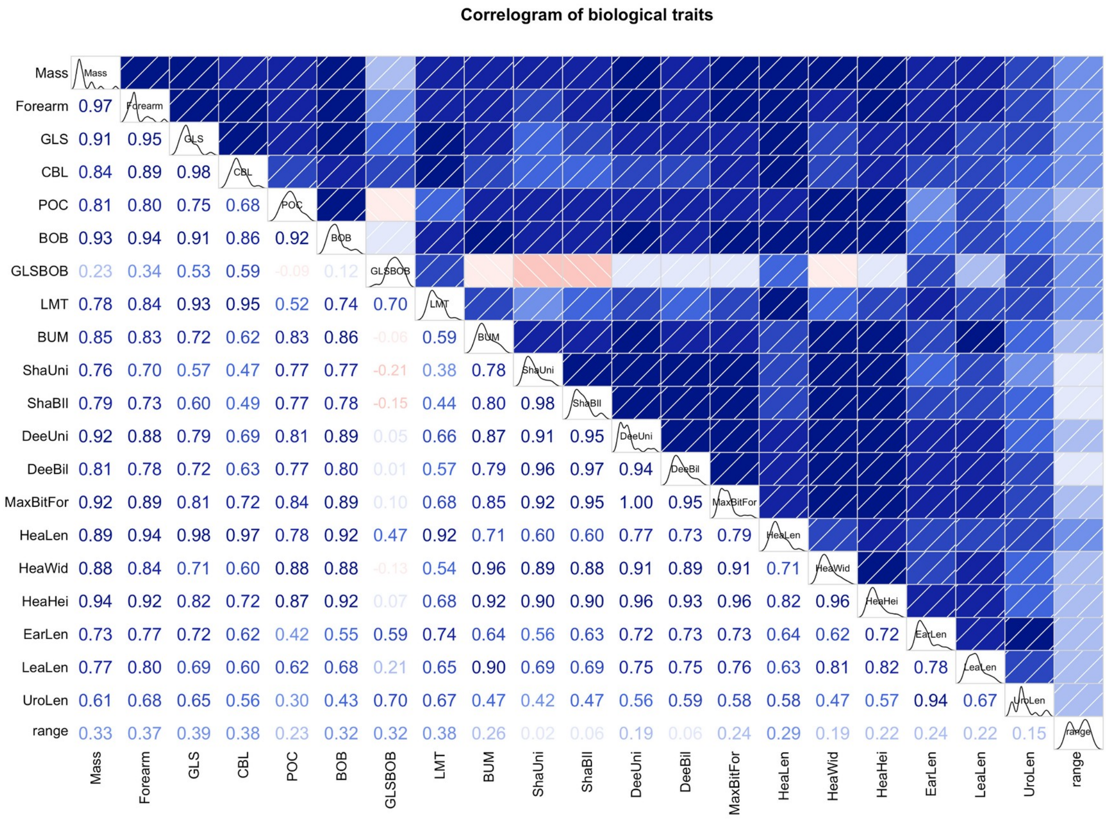
**Supplementary Figure 12. Dual**



## Supplementary Figure 13. Multilayer



## Supplementary Figure 14. Morphometric traits




Legend: Mass = Body mass, FA = Forearm length, GLS = Greatest length of skull, POC = Width across post-orbital constriction, BOB = Breadth of braincase, LMT = Length of maxilary toothrow, BUM = Breadth across upper molars, ShaUni = Shallow unilateral bite force, ShaBIl = Shallow bilateral bite force, DeeUni = Deep unilateral bite force, DeeBil = Deep bilateral bite force, MaxBitFor = Max bite force, HeaLen = Head length, HeaWid = Head width, HeaHei = Head height, EarLen = Ear length, LeaLen = Nose leaf length, UroLen = Uropatagium length, range = Geographic range size.

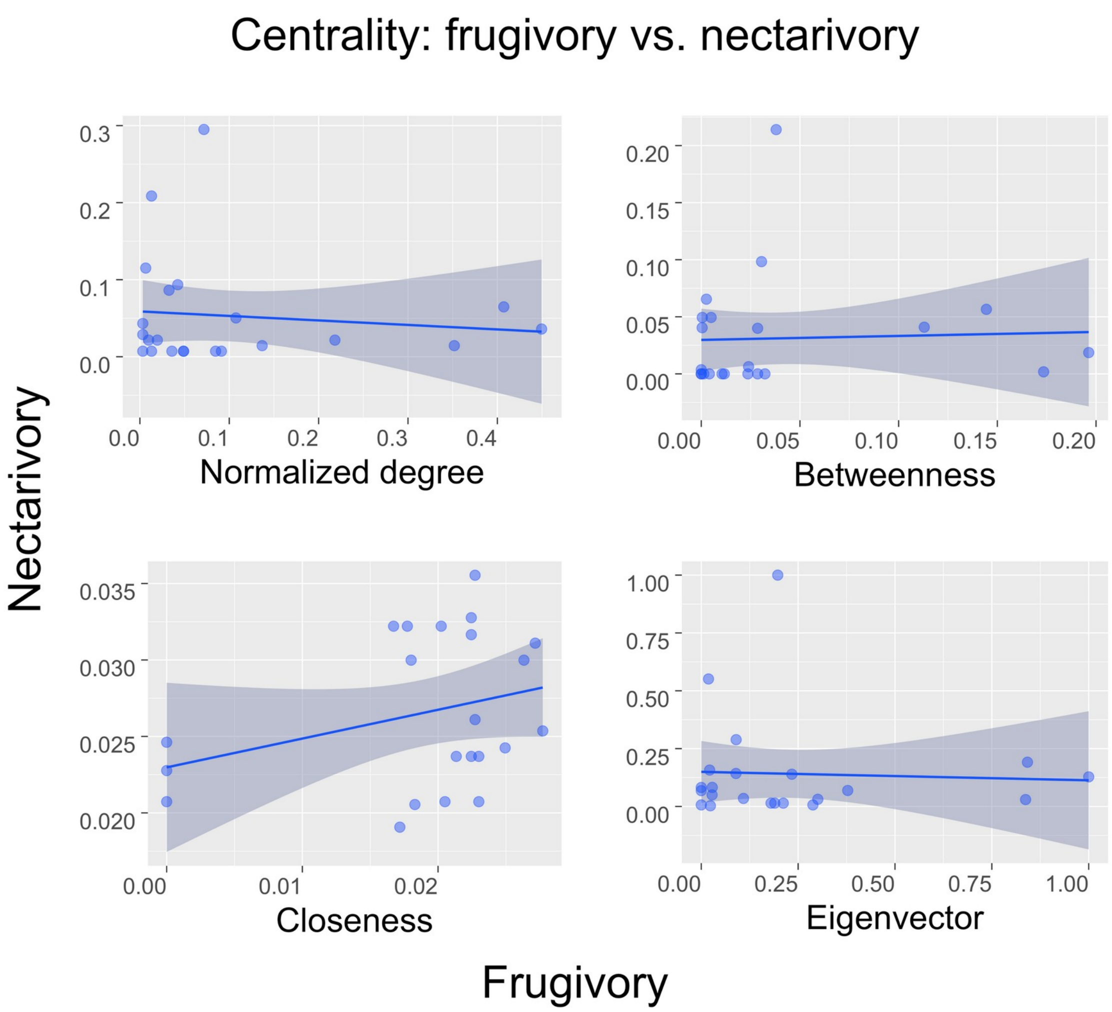
## Supplementary Results 2

Relationships between centrality metrics and results of the latent variable analysis.

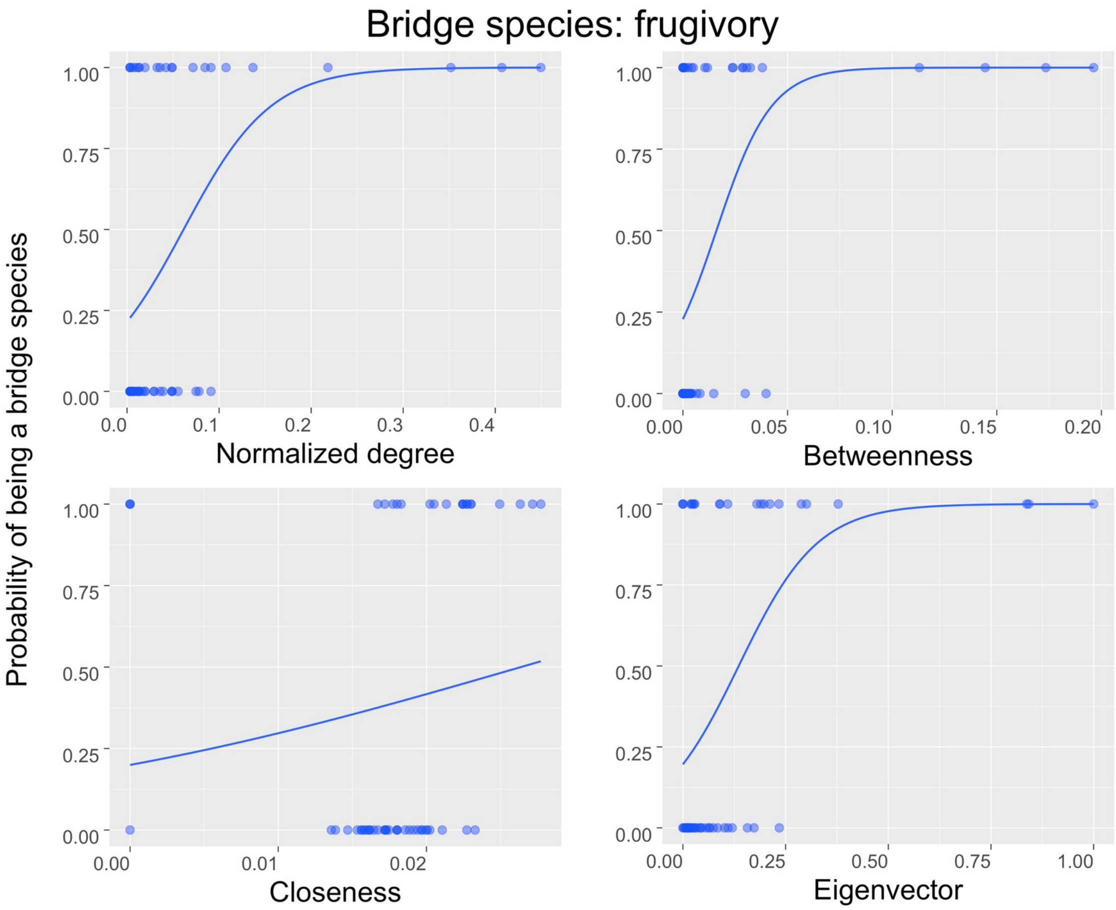
### Supplementary Figure 15. Relationships between centrality metrics.

(A) Relationships between the four most important centrality metrics between layers for bat species that made interactions of frugivory and nectarivory. (B) Probability of a bat being a bridge species (i.e., making both frugivory and nectarivory interactions) as a function of its centrality in the frugivory layer, as given by four metrics. (C) Probability of a bat being a bridge species (i.e., making both frugivory and nectarivory interactions) as a function of its centrality in the nectarivory layer, as given by four metrics. See test results in the main text (Table 3).

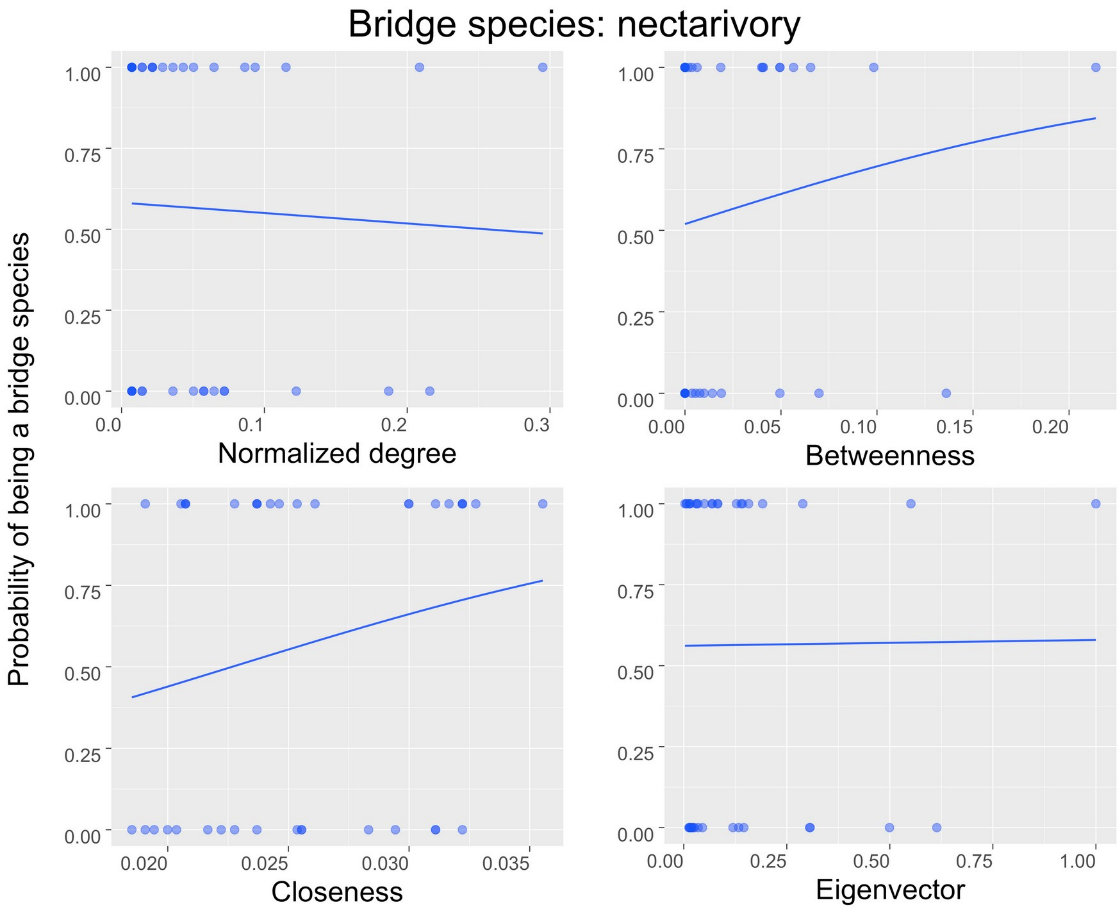
A.



B.


Bridge species: frugivory
Probability of being a bridge species
1.00
0.75
0.50
0.25
0.00
0.0
0.1
0.2
0.3
0.4
Normalized degree
0.00
0.05
0.10
0.15
0.20
Betweenness
0.00
0.01
0.02
Closeness
0.00
0.25
0.50
0.75
1.00
Eigenvector

C.


Bridge species: nectarivory
Probability of being a bridge species
1.00
0.75
0.50
0.25
0.00
0.0
0.1
0.2
0.3
Normalized degree
0.00
0.05
0.10
0.15
0.20
Betweenness
0.020
0.025
0.030
0.035
Closeness
0.00
0.25
0.50
0.75
1.00
Eigenvector

## Supplementary Table 1. Results of the latent variable analysis.

We present only the results obtained for the models and the latent variables and the single indicator variable: skull morphology (*skull*), bite force (*bite*), body size (*size*), and geographic range size (*range*).

| Layer | d.f. | $\chi2$ | Estimate | Std. Error | z-value | P |
|---|---|---|---|---|---|---|
| **Frugivory** | | | | | | |
| model | 29 | 155.962 | | | | 0.000 |
| size | | | -0.524 | 0.176 | -2.972 | 0.003 |
| bite | | | 1.585 | 0.193 | 8.205 | 0.000 |
| skull | | | -4.808 | 8.289 | -0.580 | 0.562 |
| range | | | 0.152 | 0.173 | 0.877 | 0.381 |
| **Nectarivory** | | | | | | |
| model | 29 | 149.493 | | | | 0.000 |
| size | | | 1.268 | 0.200 | 6.334 | 0.000 |
| bite | | | -1.841 | 0.218 | -8.431 | 0.000 |
| skull | | | 0.803 | 2.071 | 0.388 | 0.698 |
| range | | | 0.361 | 0.197 | 1.835 | 0.066 |
| **Multilayer** | | | | | | |
| model | 29 | 163.342 | | | | 0.000 |
| size | | | 0.292 | 0.192 | 1.521 | 0.128 |
| bite | | | 0.517 | 0.208 | 2.487 | 0.013 |
| skull | | | -4.275 | 8.963 | -0.477 | 0.633 |
| range | | | 0.181 | 0.188 | 0.960 | 0.337 |

## Supplementary Glossary 1

A small dictionary of network science. In some cases, the same entities are represented by different terms in network theory and graph theory. There is also conflict with the ecological terminology. Terms explained circularly in this dictionary are written in *italics*. For further vocabulary, explanations, and mathematical definitions, consult the specialized literature[1–7].

### Supplementary Table 2. Glossary

| Term | Definition and usage |
|---|---|
| Adjacency matrix | A matrix that defines which *nodes* in a *graph* are connected to one another by a *link*. In the case of a bipartite network, when the matrix contains nodes of one class in the rows and nodes of the other class in the columns, it is also called an incidence matrix. |
| Average path length | A metric of *connectivity*. Considering all small *paths* between all pairs of *nodes* in a *network*, the average path length is the arithmetic mean of the length of those small paths. For example, "six degrees of separation" is a concept related to how many social relationships, on average, separate any two persons in the world. |
| Betweenness | A metric of *centrality*. The proportion of *small paths* in the *network* in which the *node* is present. For example, a bat species that feeds on flower species of different *modules* in a network is expected to have high betweenness, as it is a bridge between regions of the network. |
| Binary | A *link* whose value is either 0 or 1. A *network* based on presence or absence of links is called binary. For example, a bat species visiting or not visiting a plant species in a pollination network. Synonym for *qualitative*. |
| Bipartite | A *network* with two classes of *nodes*, in which *links* may exist only between nodes of different classes. For example, a network formed between nectarivorous bat species and the plant species visited by them: bats may visit plants, but not other bats. Synonym for *two-mode network*. |
| Centrality | The relative importance of a *node* to the *topology* of its *network*. There are many different concepts of centrality focused on different aspects of a node's importance. For example, the *degree* of a node is a kind of centrality. |
| Class | A category of *nodes* in a *network*. For instance, in the studied system, bats represent one class, and plants another. |
| Closeness | A metric of *centrality*. The average number of *small paths* that separates a given *node* to any other nodes of the same *network*. For example, a bat species that visits flower species visited by many other bats in a network is expected to have high closeness. In other words, it has a very common niche. |
| Combined | A *network* with two predominant *topologies*, usually hierarchical to one another. For instance, a network that has a *modular* topology, and whose modules that are internally *nested*. |
| Complementary specialization | A *connectivity* metric. It assesses how much the *nodes* in a *network* establish unique *links*. For example, in a bat-plant network, if each bat species visits a different *set* of plant species, and niche overlap is close to zero, then the network scores high complementary specialization; in other |

words, the bat species play complementary functional roles.

**Complex system** — A *system* whose properties cannot be inferred only from its *elements* or *connections* is called a complex system. The properties of a complex system emerge from its assembly, and so they are called emergent properties. For example, a *network* may be *nested*, but a *node* may not.

**Connectance** — A metric of *connectivity*. The proportion of *links* observed in a *network* in relation to the number of potential links it could maximally have. For example, interaction types with higher specificity, such as parasitism, are expected to form networks with lower connectance than interaction types with lower specificity, such as seed dispersal.

**Connection** — When two *nodes* share some kind of relationship between them in a *network*. A connection may be of different kinds, including *relations* and *links*.

**Connectivity** — The number and distribution of *links* in a *network* or *links* in a *graph*. For example, if two networks have the same *size*, but one has fewer links, it has lower connectivity. Another example: if two networks have the same size and *degree*, but one is *nested* and the other is *modular*, they have different connectivity.

**Degree** — A metric of *centrality*. The number of links that a *node* has in a *network*, or the number of *nodes* in a *graph*. For example, a bat species that visits several flower species in a network has higher degree than a bat species that visits few flower species.

**Drawing** — The visual representation of a *network* or *graph*. There are several methods for drawing networks and graphs, based on algorithms focused on highlighting different properties of the *system*. For instance, *bipartite* algorithms emphasize the different sets of nodes in the network, while energy-minimization algorithms emphasize the *centrality* of different *nodes* and the *modularity* of the network.

**Edge** — Used in *graph* theory. Synonym for *link*.

**Element** — An entity that belongs to a *set* or a *system*.

**Emergent property** — A property that emerges from the assembly of a complex *network*. Emergent properties may be weak, when they exist by definition, or strong, when they emerge from the *system*. For example, if a bat-plant network is *nested*, *nestedness* is one of its weak emergent properties, while *robustness* to extinctions may be one of its strong emergent properties.

**Foodweb** — A *network* whose *links* represent trophic interactions (“who eats whom?”). For example, a network formed by bats and their predators, or bats and their prey.

**Graph** — Used in graph theory. A *set* of *nodes* (*elements*) and the *edges* (*connections*) between those nodes. Graphs are abstract systems studied in pure mathematics. When a graph is studied in applied mathematics and represents a real-word system, it is called a *network*.

**Interlayer link** — A *link* between *nodes* that belong to the same *layer* of a *multilayer network*. Synonym for a *relation*.

**Intralayer link** — A *link* between *nodes* that belong to different *layers* of a *multilayer network*.

**Layer** — A set of *links* of one type in a *multilayer network*. For example, in a bat-plant network that contains two types of interactions, let us say frugivory and nectarivory, the interactions of frugivory form one layer of the network.

| | |
|---|---|
| Link | Used in *network* theory. A *connection* between nodes in a network. For example, an interaction of pollination between a bat species and a plant species. Synonym for *edge*. |
| Modular | A *network* in which *modularity* predominates as a *topology*. For example, a pollination network in which different plant families form separate subgroups visited by different bat species. |
| Modularity | The *topology* of a *network* in terms of how many *modules* it contains and how much *connectivity* there is between those modules. |
| Module | A subgroup of *nodes* in a *network* that are more densely (in a *binary* network) or strongly (in a *weighted* network) connected to one another than to other nodes of the same network. It may also refer to a subgroup of links in a network that share a very similar subgroup of nodes. For example, in a bat-plant network, a subgroup of bat species that feed on the same plant species. |
| Multilayer | A *network*, in which two *nodes* may be connected to one another by different types of relations and *links*. The types of relations may be different kinds of ecological interactions, as in the present study. The types of links are *intralayer* and *interlayer*. For example, a network formed by bats and the plants that they visit to feed on fruits (layer 1) or nectar (layer 2) has two types of relation. In the present study, the system assessed fits the subcategory of a *multiplex network*. |
| Multilink | A connection between two *nodes* that fits two or more categories of *links* in a *multilayer network*. |
| Multipartite | A *network* that is divided into three or more *sets* of *nodes*, in which links may exist only between nodes of different sets. For example, a network formed by nectarivorous bats, the plant species visited by them, and the ectoparasites of those bats. Tripartite *foodwebs* are also called tritrophic networks. |
| Multiplex | A multilayer network in which all *nodes* are present on all *layers*, the layers have equal sizes, and *interlayer links* occur only between shared nodes. |
| Nested | A *network* in which *nestedness* predominates as a *topology*. For example, a pollination network, in which the plant species visited by a bat species with lower *degree* are also visited by a bat species with higher degree. |
| Nestedness | The *topology* of a *network* in terms of how much the *links* of *nodes* with lower degree represent a subset of the links of nodes with higher degree. |
| Network | Used in *network* theory. A *set* of *nodes* (*elements*) and the *links* (*connections*) between those nodes. For example, in Biology, real-word systems, such as ensembles formed by plants and pollinators, are modeled as networks. |
| Node | Used in *network* theory. An *element* of a *network*. For example, a bat species in a pollination network at the community level. Synonym for *vertex.* |
| One-mode | See *unipartite*. |
| Path | A *set* of *links* in a *network* that connect two *nodes*. A *small path* is a |

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| | geodesic, i.e., the smallest set of links between two nodes. |
| Projection | A *subnetwork* formed by one set of *nodes* from a *multipartite network*. For example, in a bat-plant network, if one builds a subnetwork with bat species only, in which two bat species are connected to one another by a *link* when they share at least one plant species, this is a *unipartite* projection. |
| Qualitative | The same as a *binary network*. |
| Quantitative | The same as a *weighted network*. |
| Relation | A type of *connection* between *elements* in a *system*, *network*, or *graph*. For instance, in the present study, a bat and a plant species may relate to one another through interactions of frugivory or nectarivory. |
| Robust | A *network* that has the *emergent property* of *robustness*. |
| Robustness | An *emergent property* of some *networks* that suffer little change in *topology* when a given proportion of its *nodes* or *links* are removed. For example, a bat-plant network is robust, when it can lose several flower species without changing from *nestedness* into another topology. |
| Size | The number of *nodes* in a *network*, or the number of *edges* in a *graph*. For example, the sum of bat and plant species in a pollination network. |
| State node | A *node* that belongs to two or more *layers* of a *multilayer network*. |
| Subnetwork | A subset of the *nodes* and *links* of a *network*. For example, in a bat-plant network that includes different plant families, if one builds a network with only the Piperaceae and the bat species that visit those plants, this is a *subnetwork*. |
| System | A *set* of *elements* and the *connections* between those *elements*. *Networks* and *graphs* are kinds of systems. |
| Topology | The structure of a *network* or *graph* in terms of *degree*, *size*, and *connectivity*. For example, *nestedness* and *modularity* are two kinds of topology. |
| Tripartite | A *network* with three *classes* of *nodes*, in which *links* may exist only between nodes of different classes. For instance, a network formed by plants, herbivores, and parasitoids of the herbivores. |
| Two-mode | See *bipartite* network. |
| Unipartite | A *network* that that contains a single *class* of *nodes*, in which *links* may exist between any nodes. For example, a network of niche overlap between bat species. Synonym: *one-mode network*. |
| Vertex | Used in *graph* theory. An *element* of a graph. Synonym for *node*. |
| Weighted | A *link* to which some weight is attributed. A *network* based not only on presence or absence of links, but also on the weight of those links, is called weighted. For example, the frequency of visits observed in the field of a given bat species to a given plant species may be used to attribute a weight to the link between them. Synonym for *quantitative*. |

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